NUMERICAL SIMULATION OF THE FLOW AROUND A FLYING VEHICLE WITH HIGH SPEED AT HIGH ALTITUDE

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ABSTRACT

A significant portion of the flight trajectory of a reusable launch vehicle is hypersonic speed at extremely high altitudes. Therefore, they are in the low Reynolds number and high Mach number ranges. The flow around these vehicles falls into the transitional regime. In general, the Knudsen number in the transitional regime is between 0.01 and 10. Since there is no appropriate ground test facility to provide windtunnel data, and flight experiment data are very expensive, the only alternative is numerical simulation.

As the Knudsen number increases, the Navier-Stokes equations gradually deteriorate because the transitional nonequilibrium effect prevails. It is natural to consider the Boltzmann equation as the governing equation for the transitional flow problems. The Boltzmann equation describes phenomena in gases at arbitrary Knudsen number, and is used as a governing equation for whole flow regime. It includes the continuum, transitional and free molecular flow regimes. However, the full Boltzmann equation is very difficult to solve because the collision term is very complex physically as well as numerically. Therefore, many investigations attempt to simplify the collision terms to solve the Boltzmann equation for the transitional flow. One such attempt is the Chapman-Enskog expansion method. As a consequence of the Chapman-Enskog expansion, the Euler equations are based on the zero-th order approximation. The Navier-Stokes equations are derived from the first order approximation. Based on a second order approximation of the expansion, the resulting equations of conservation of mass, momentum and energy are the Burnett equations. Recently, many researchers have pointed out that the Burnett equations are more accurate than the Navier-Stokes equations.

In this study, the newly developed Burnett equations solver was used to obtain the Burnett solutions. Validations of the Burnett equations solver code were performed for flow past an ellipsoid and a elliptic cylinder at Mach number 2 and 5 with various Reynolds numbers. In tests, it was found that the Burnett equations can be used to provide better results than the Navier-Stokes solutions, but for a larger Knudsen number, it failed. For the transitional flow with large Knudsen number the DSMC method is the only alternative of the numerical approach.